

STAR Physics Program

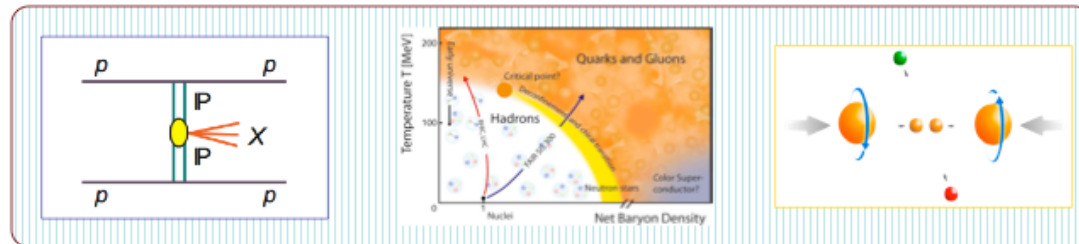
STAR Five-year Beam Use Request for FY09-13

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for the STAR Collaboration

Nuclear Science Division

Lawrence Berkeley National Laboratory



1) Introduction

2) STAR Physics Results

- **Spin:**
- Heavy Ion:
- Run 8 performance:

3) STAR Hardware Upgrades

- DAQ1000:
- MRPC TOF:

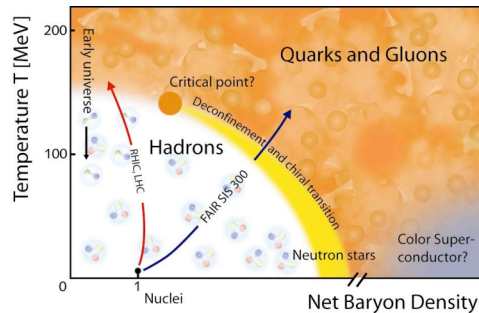
4) BUR for Runs 09 - 13

- **Runs 9 -10:**
- Runs 11 - 13:

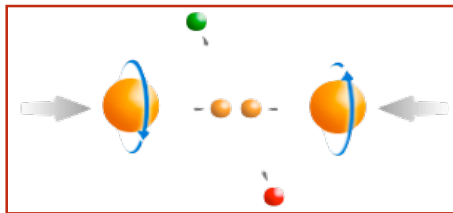
5) Summary



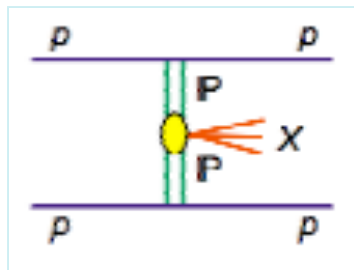
STAR Physics Focus at the QCD Lab



- 1) Heavy-ion program
 - Study **medium properties, EoS**
 - pQCD in hot and dense medium
- 2) RHIC beam energy scan
 - Search for **critical point**
 - Chiral symmetry restoration

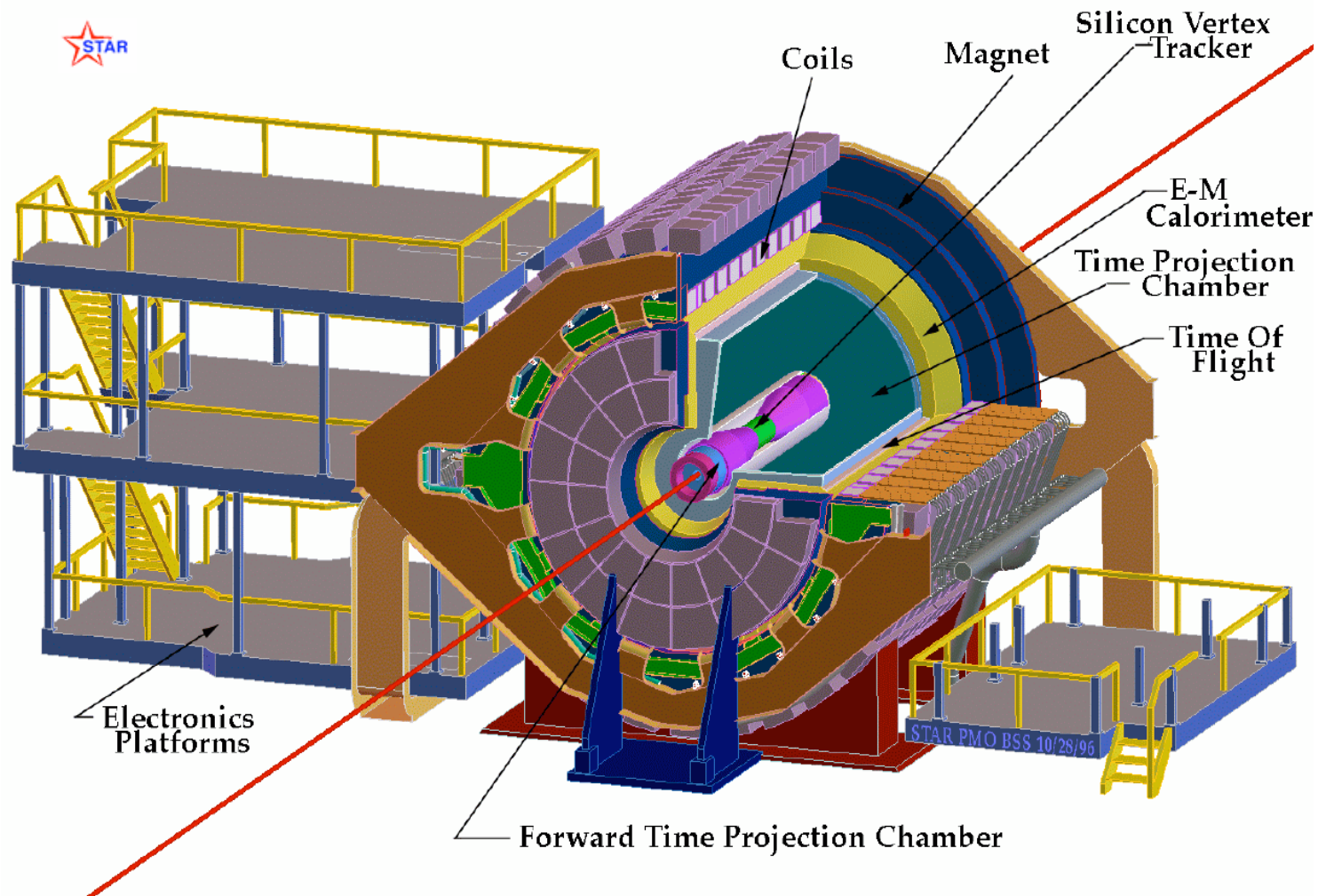


- 1) Longitudinal and transverse spin programs
 - Study **proton intrinsic properties**
- 2) Forward programs
 - Study low-x properties and search for **CGC**

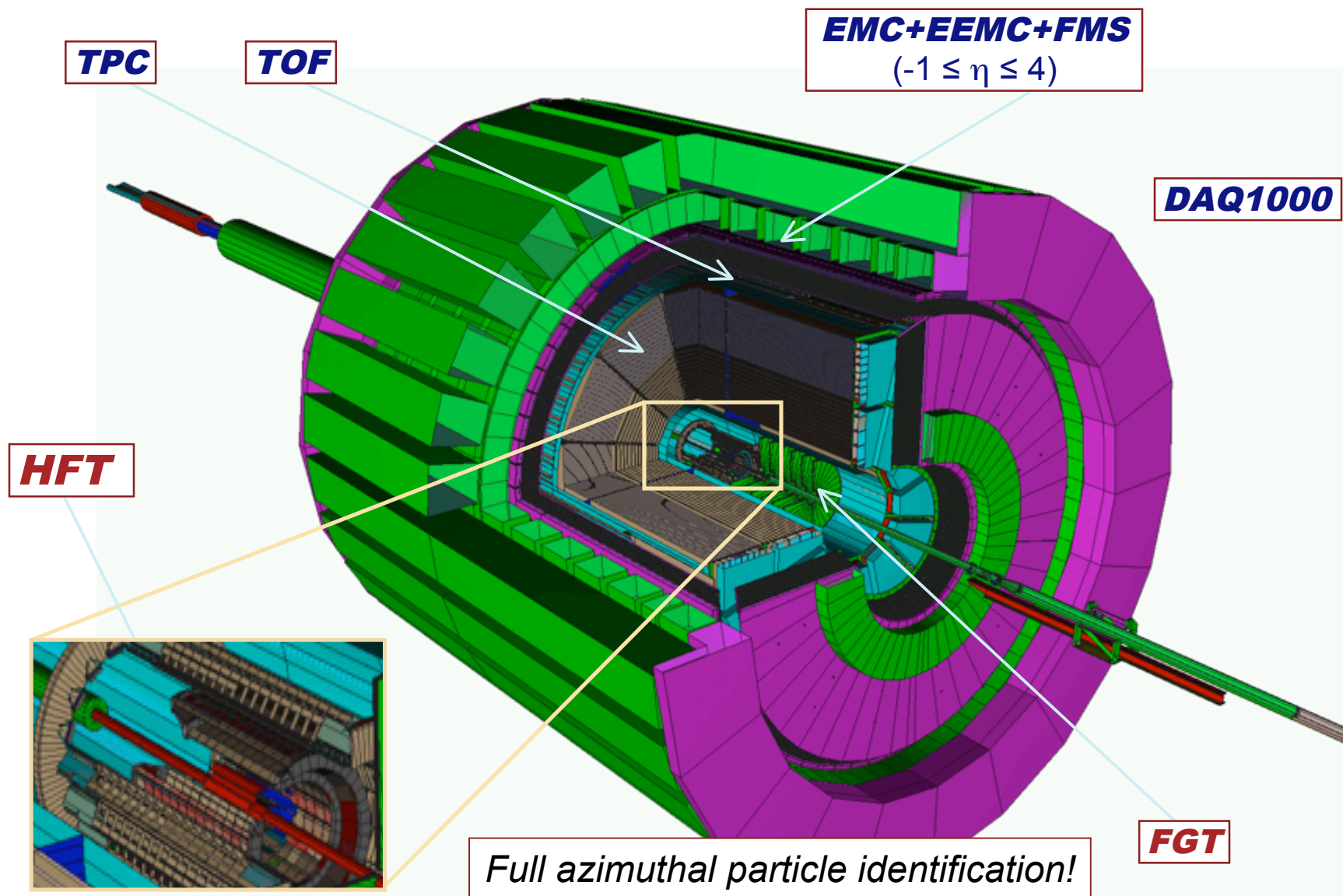


- Tagged forward protons
- Study elastic and inelastic process
 - Investigate **gluonic exchanges** and search for **gluonic matter**

STAR Detector



STAR Detectors



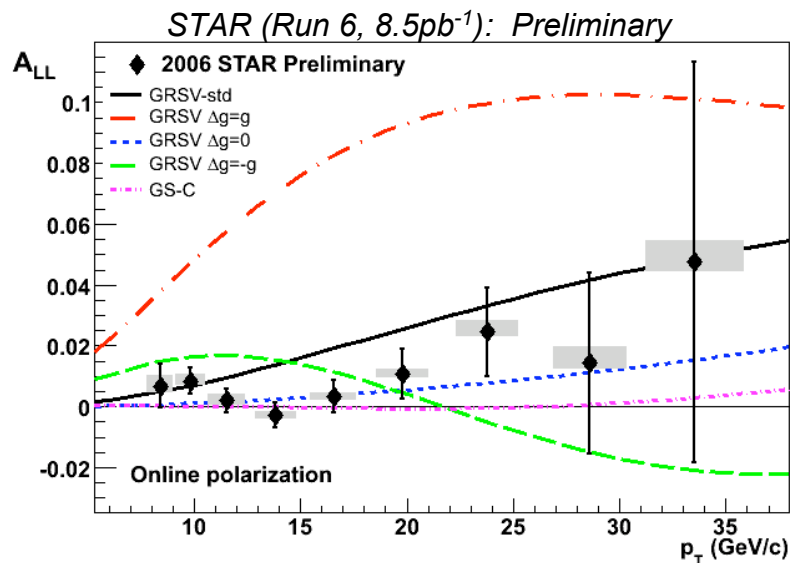
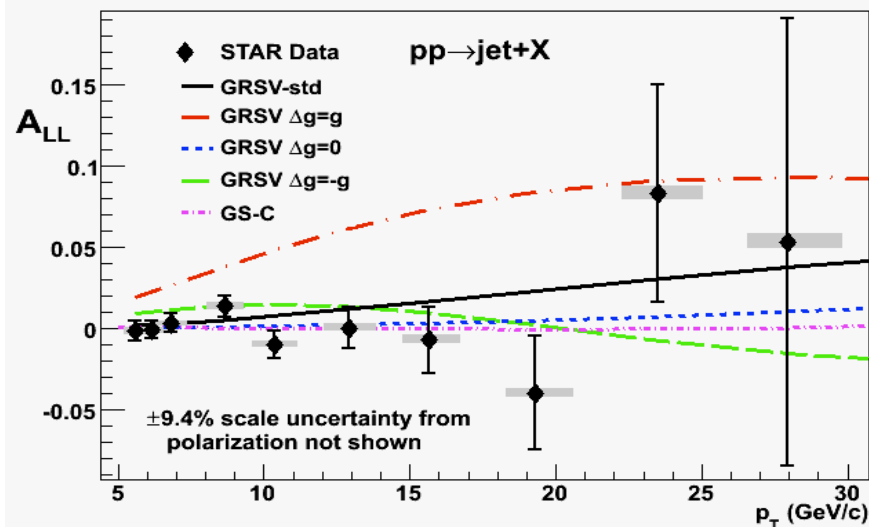
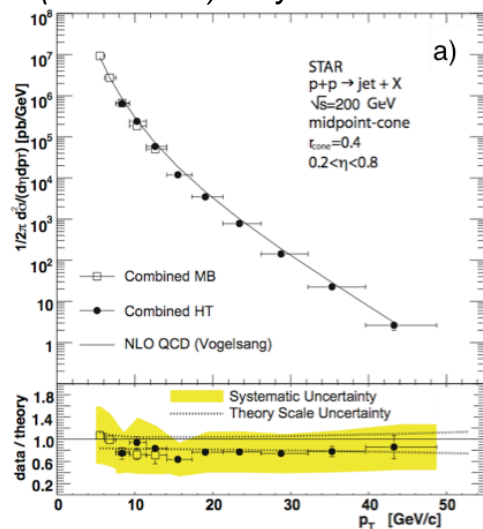
Selected STAR Spin Results



STAR Spin Results

STAR (Runs 3 & 4): Phys. Rev. Lett. **97**, 252001(2007)

STAR (Run 5): sub. to Phys. Rev. Lett. arXiv: 0710.2048



- Our A_{LL} measurement for inclusive jets has gained significant precision and kinematic reach from Runs 3 & 4 (published) to Run 5 (sub.) and, once more, to Run 6.
- Have placed significant new constraints on the magnitude of ΔG for $0.02 < x < 0.3$. Our most precise data to date (Run 6) remain statistics limited.

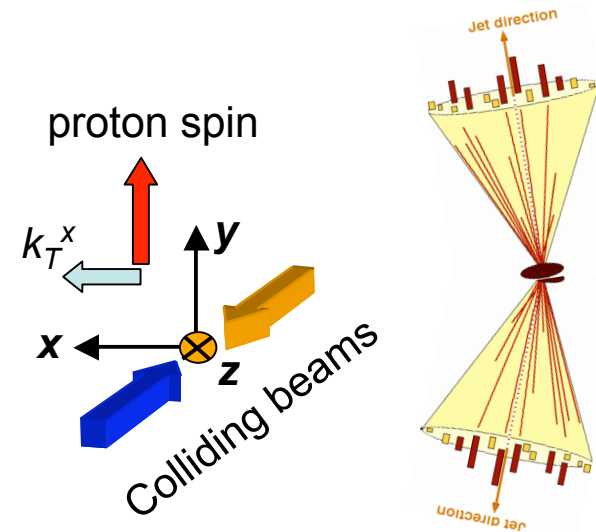
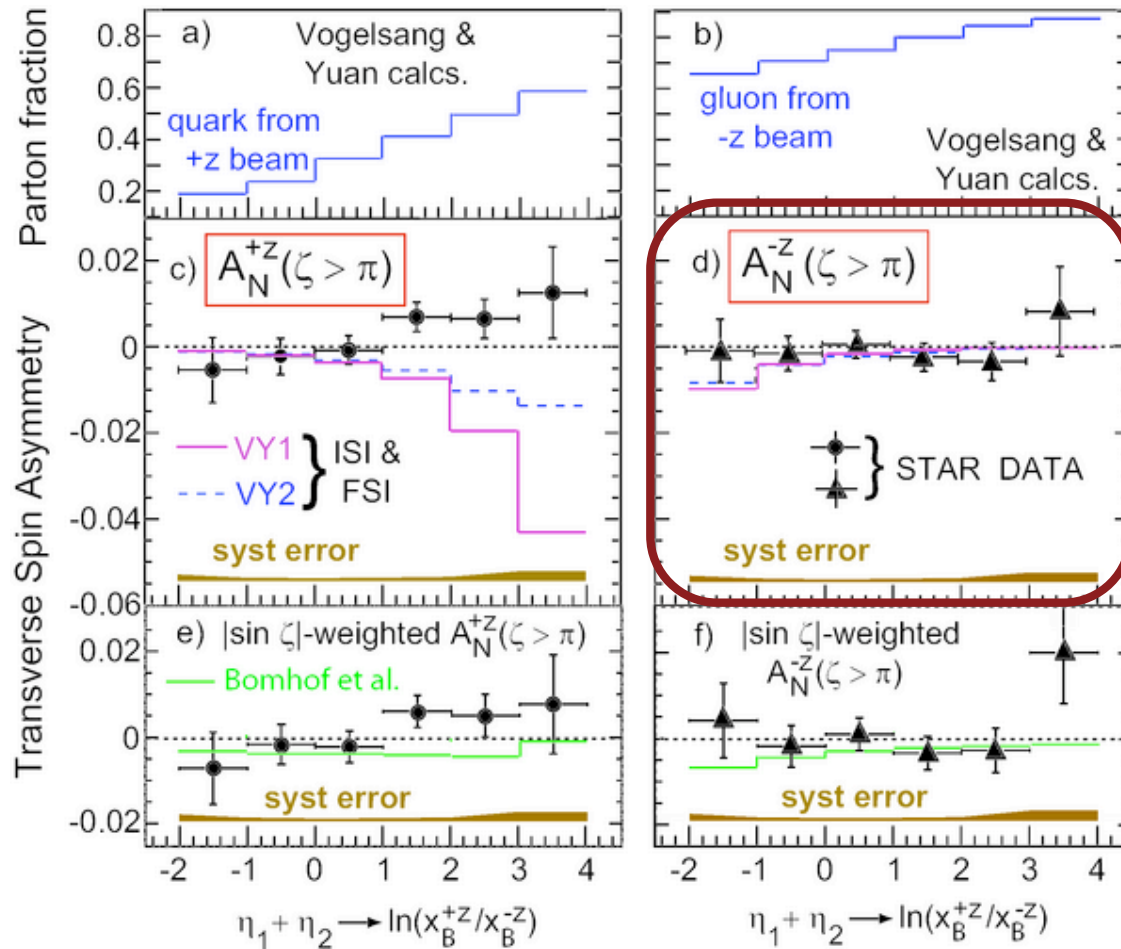


STAR Transverse Spin Results

STAR, *Phys. Rev. Lett.* **99**, 142003(2007)
arXiv: 0801.2990

STAR data from Run 6 and compared with theoretical calculations

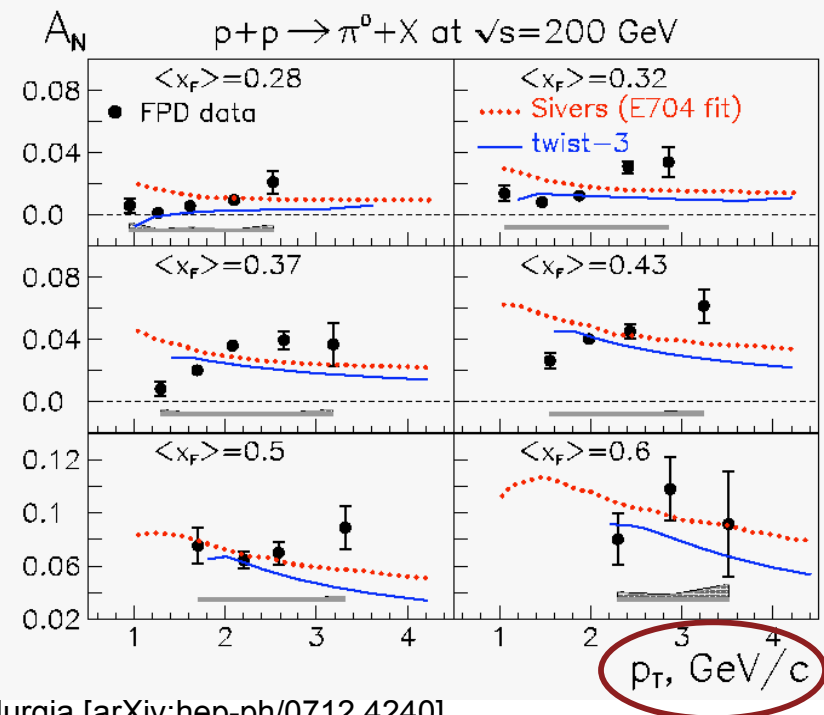
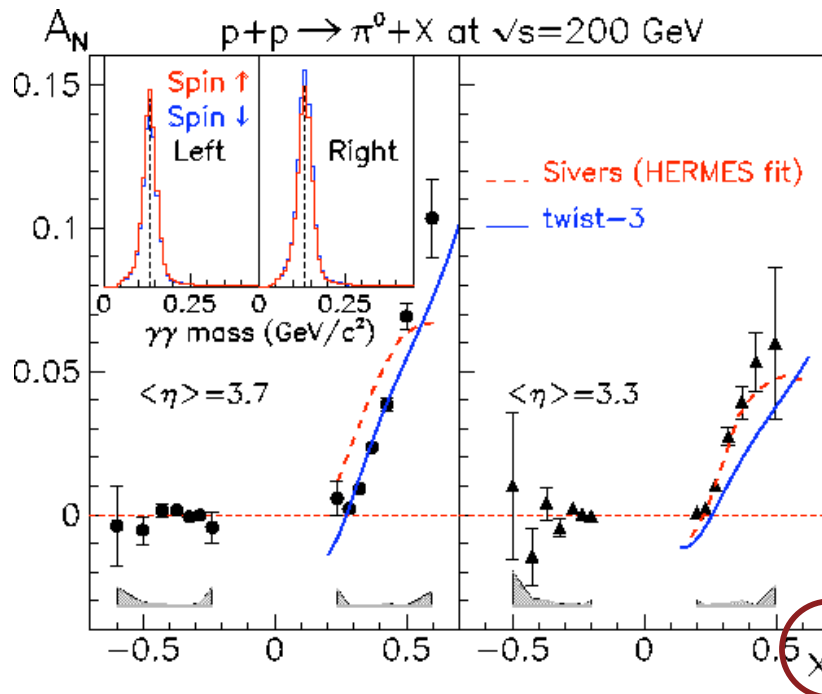
⇒ First STAR **di-jet analysis** using jets from calorimeters, has been published
unexpected smallness observed for the Sivers transverse spin phenomena for $-1 < \eta < 2$





$A_N(x_F)$ for Forward π^0 Production

STAR: Sub. to PRL, hep-ex/0801.2990



Theory (Red): M. Boglione, U. D'Alesio, F. Murgia [arXiv:hep-ph/0712.4240]

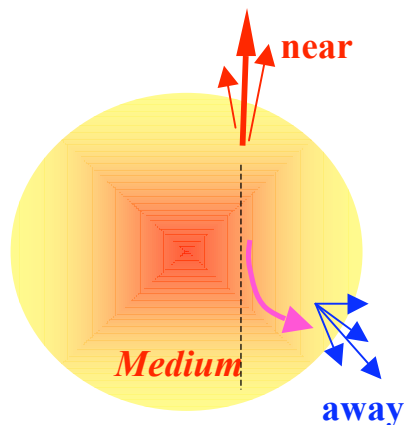
Theory (Blue): C. Kouvaris, J. Qiu, W. Vogelsang, F. Yuan, PRD **74** (2006) 114013

- Left:** Calculations based on phenomenological fits to SIDIS data account for x_F dependence
- Right:** Sivers mechanism based calculations require A_N to decrease with increasing p_T . This trend is not what is observed.

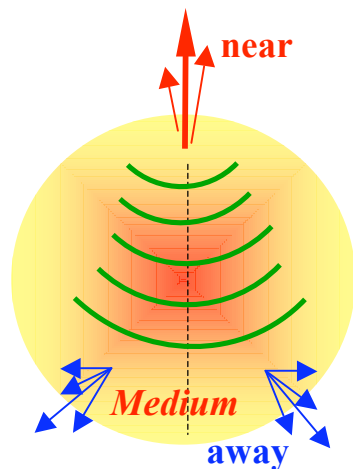
Selected STAR Heavy Ion Results

Search for Mach Cone

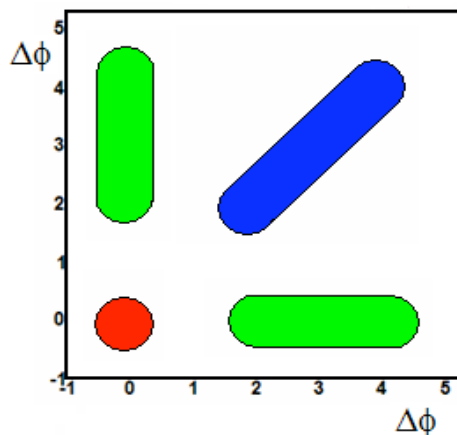
STAR: sub. to PRL, arXiv: 0805.0622 with Three Particle Correlations



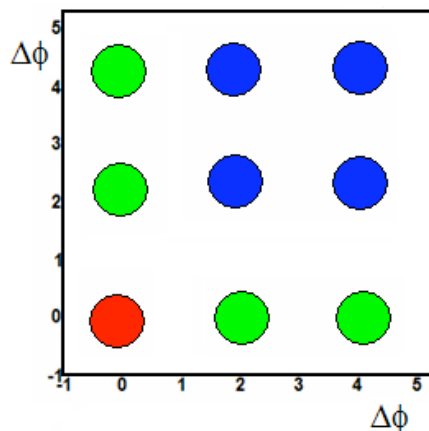
deflected jets



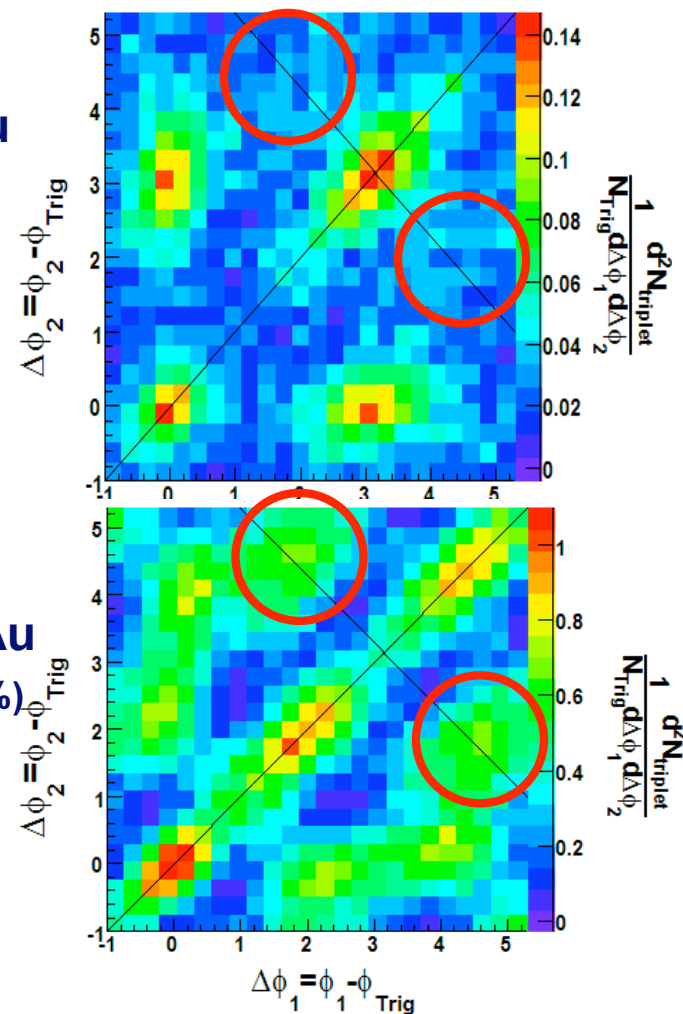
Conical Emission



d+Au



Au+Au
(0-12%)



$$\cos \vartheta^{Mach} = \sqrt{p/\varepsilon}$$

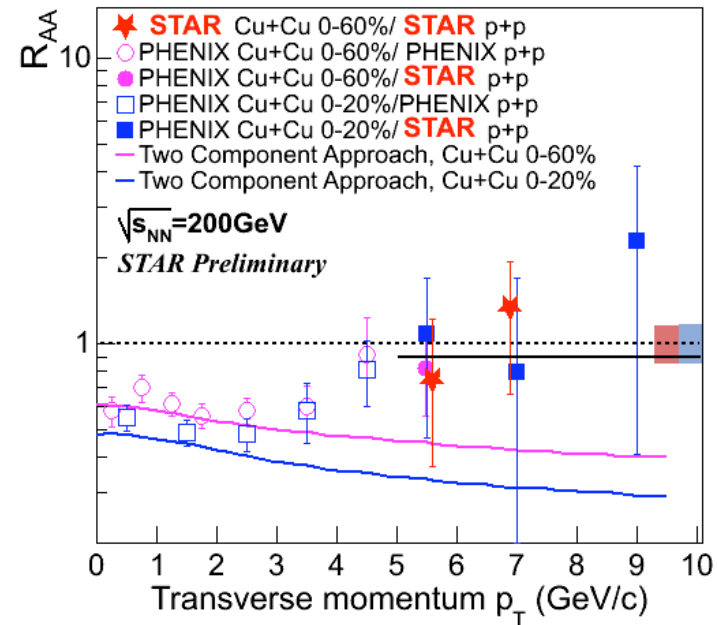
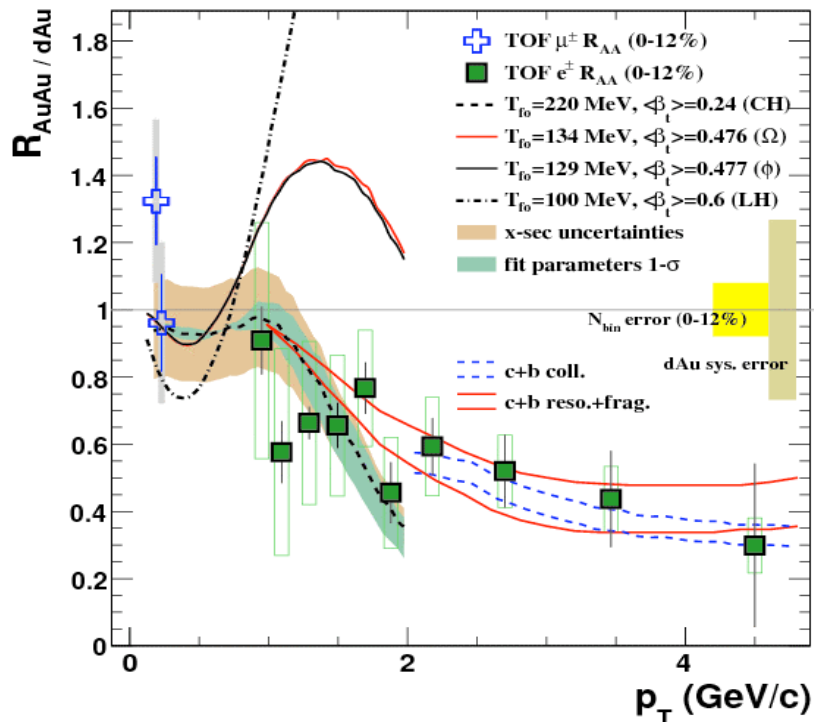
“Evidence of conical emissions ...”



Open Charm and J/ψ $R_{AA}(p_T)$

STAR: sub. to PRL, arXiv: 0805.0364

Heavy flavor hadrons freeze-out earlier than light flavor (u, d, s) hadrons



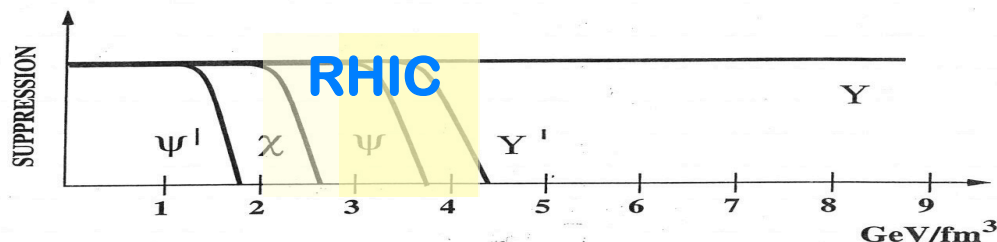
STAR Preliminary:

The Cu+Cu data consistent with no suppression at high p_T :

$$R_{AA}(p_T > 5 \text{ GeV/c}) = 0.9 \pm 0.2$$

- Low- p_T $R_{AA} \sim 0.5-0.6$ (PHENIX)
- Most models expected decrease R_{AA} at high p_T .

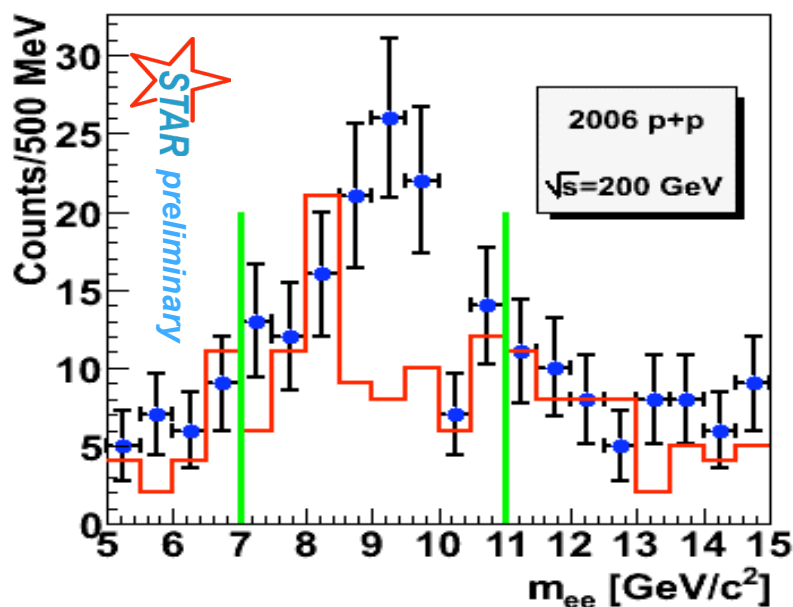
Extending to Higher Mass: Υ



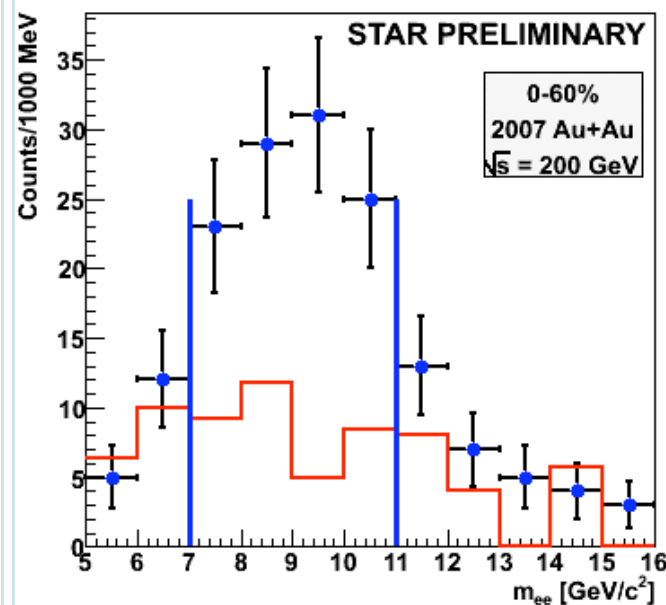
Sequential dissociation of quarkonia is sensitive to energy density of plasma

$$\Upsilon (1S+2S+3S) \rightarrow e^+e^-$$

Run 6: 200 GeV p+p

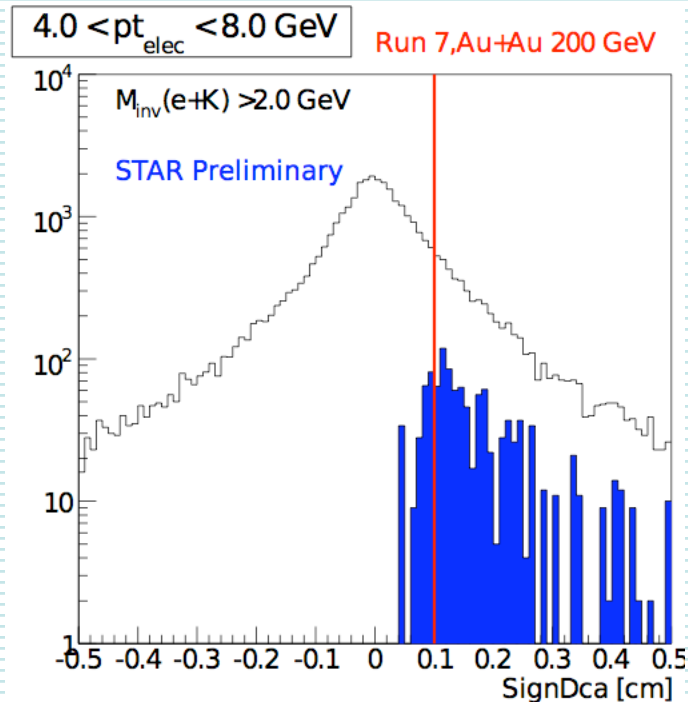
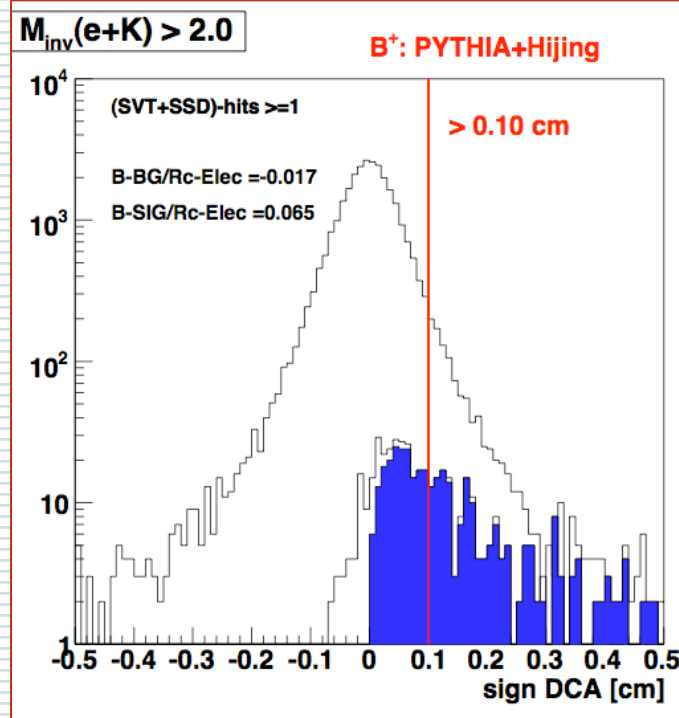


Run 7: 200 GeV Au+Au



STAR high p_T topological electron trigger works!

Bottom Decay Electron Study

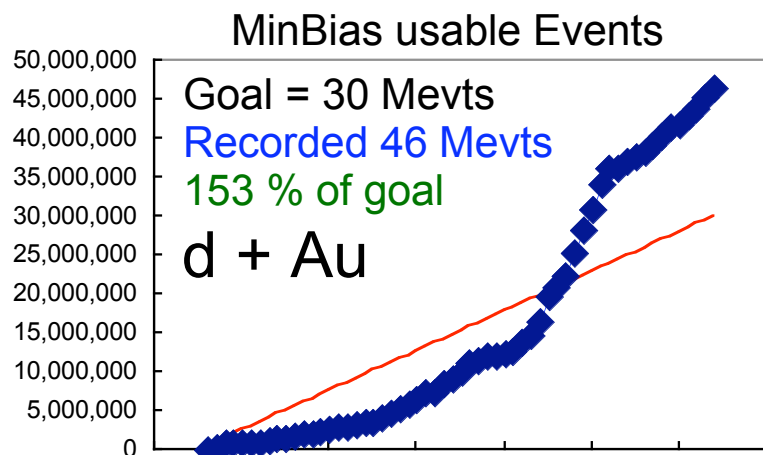


- EMC trigger + SSD+SVT vertex cuts: high energy electrons from Bottom
- In the future: HFT will provide much more powerful tool for studying heavy flavor hadron

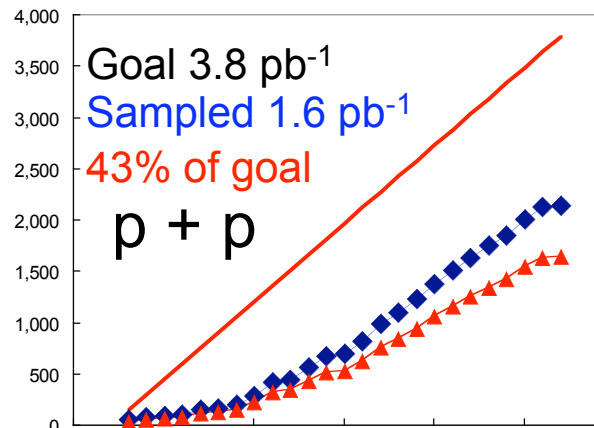
Results from Run 8



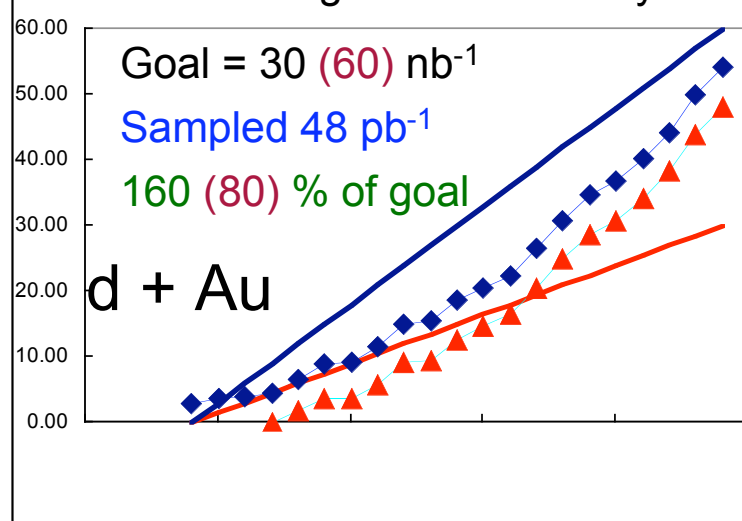
Run 8: d-Au and Polarized p+p



Integrated FMS FOM (nb⁻¹)



FMS Integrated Luminosity



I. d+Au run: **Success!**

II. Polarized p+p run:

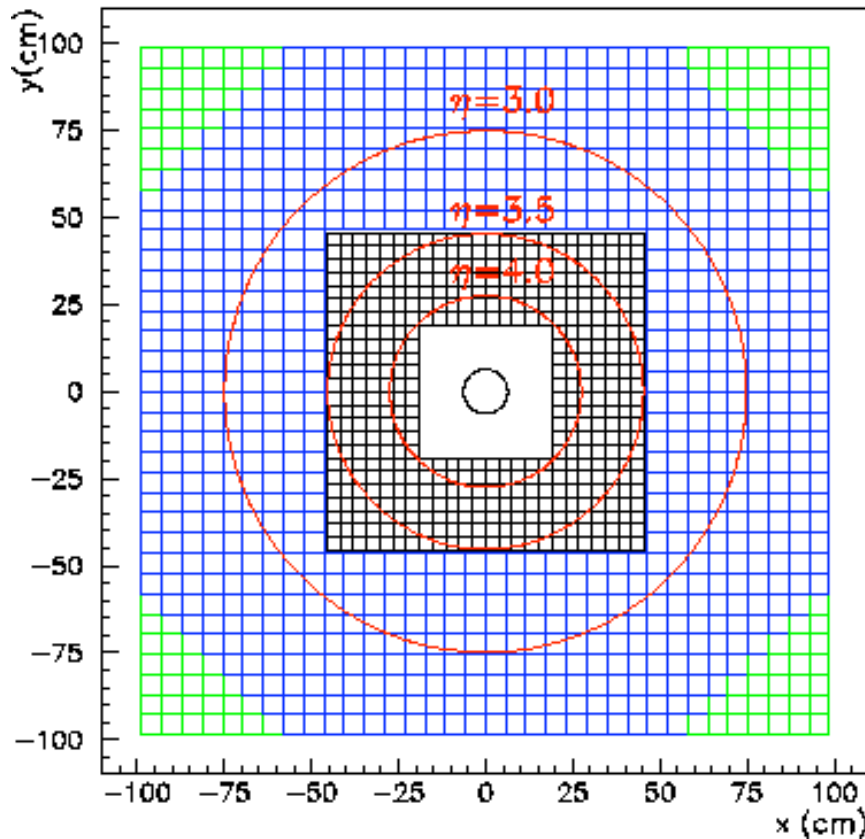
- (1) FMS CGC reference data: **Good**
- (2) Forward $A_N(x_F, p_T)$: **Short of what we had intended to achieve**
- (3) Forward direct photon asymmetries: **Not enough**
- (4) Electrons from Charm and Bottom, with low material, to resolve STAR/PHENIX discrepancy: **Good**



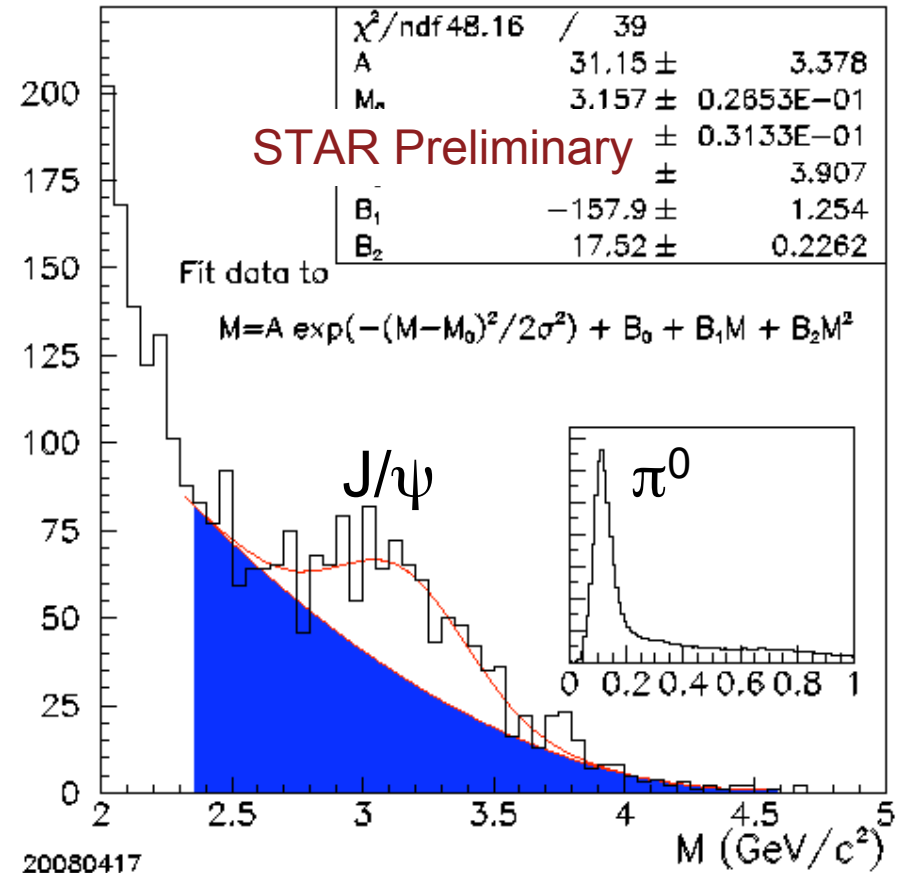
Forward Meson Spectrometer (FMS)

$2.5 \leq \eta \leq 4, 0.2 \leq x_F \leq 0.25$

476×3.8-cm cells, 788×5.8-cm cells



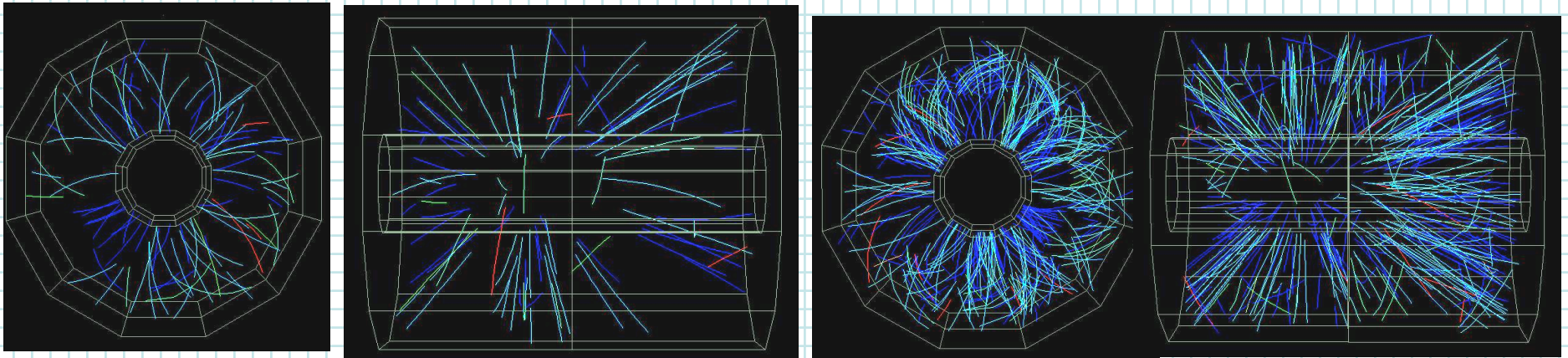
p+p, $\sqrt{s} = 200$ GeV



FMS: calibration in progress

Low Energy Test Run (9 GeV)

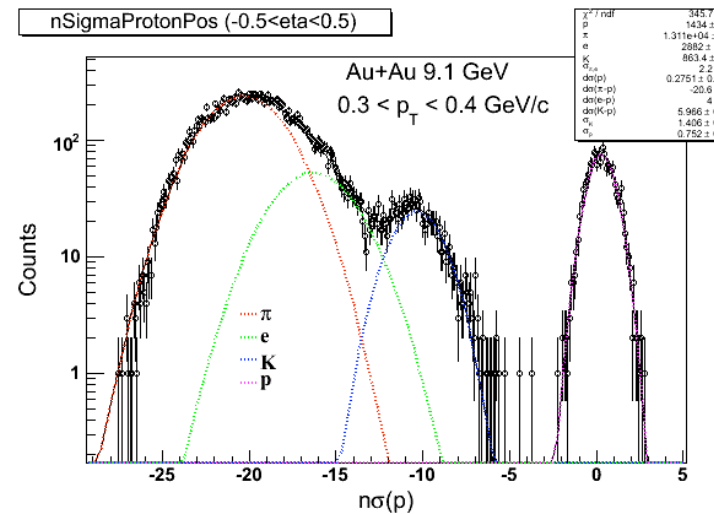
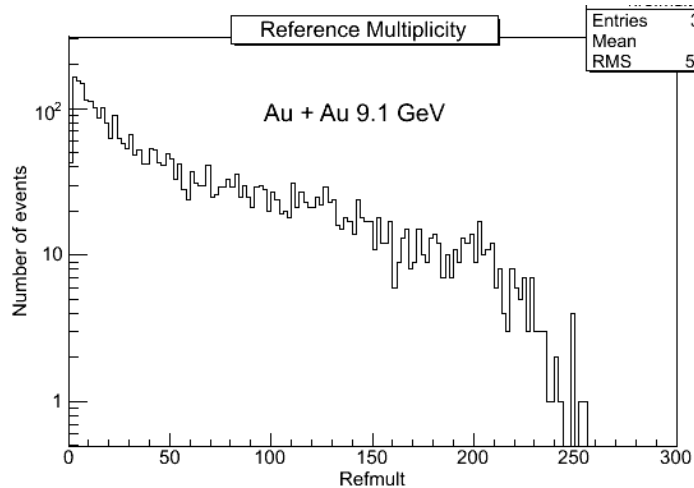
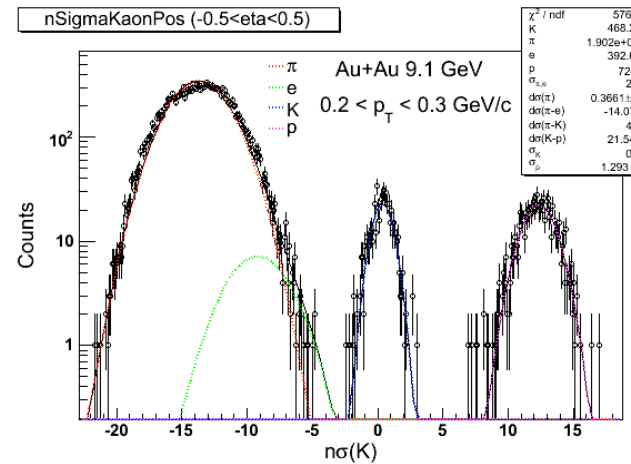
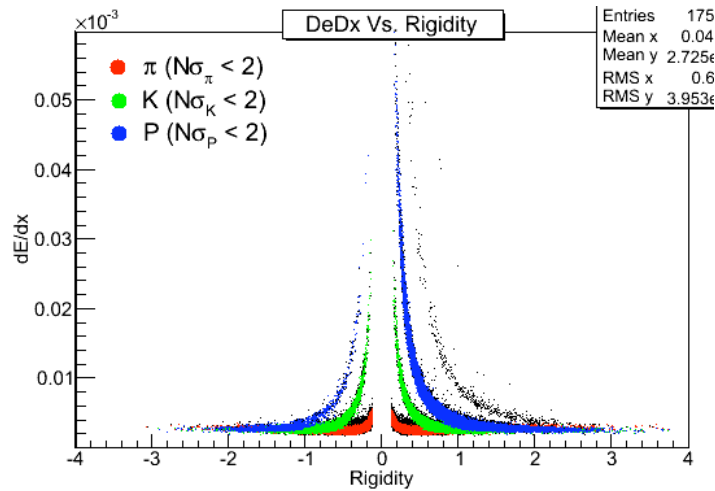
Au + Au Collisions!



- 1) ~ 3500 collisions collected
- 2) Gain understanding of triggering issues
- 3) Determine Luminosity: rate ~ 0.6 Hz at 9 GeV
- 4) STAR studying the following analysis:
Particle identification in TPC; total charged multiplicity
 π - π interferometry, particle ratios; v_1 and v_2
- 5) Physics ready with 2 - 4 Hz collisions



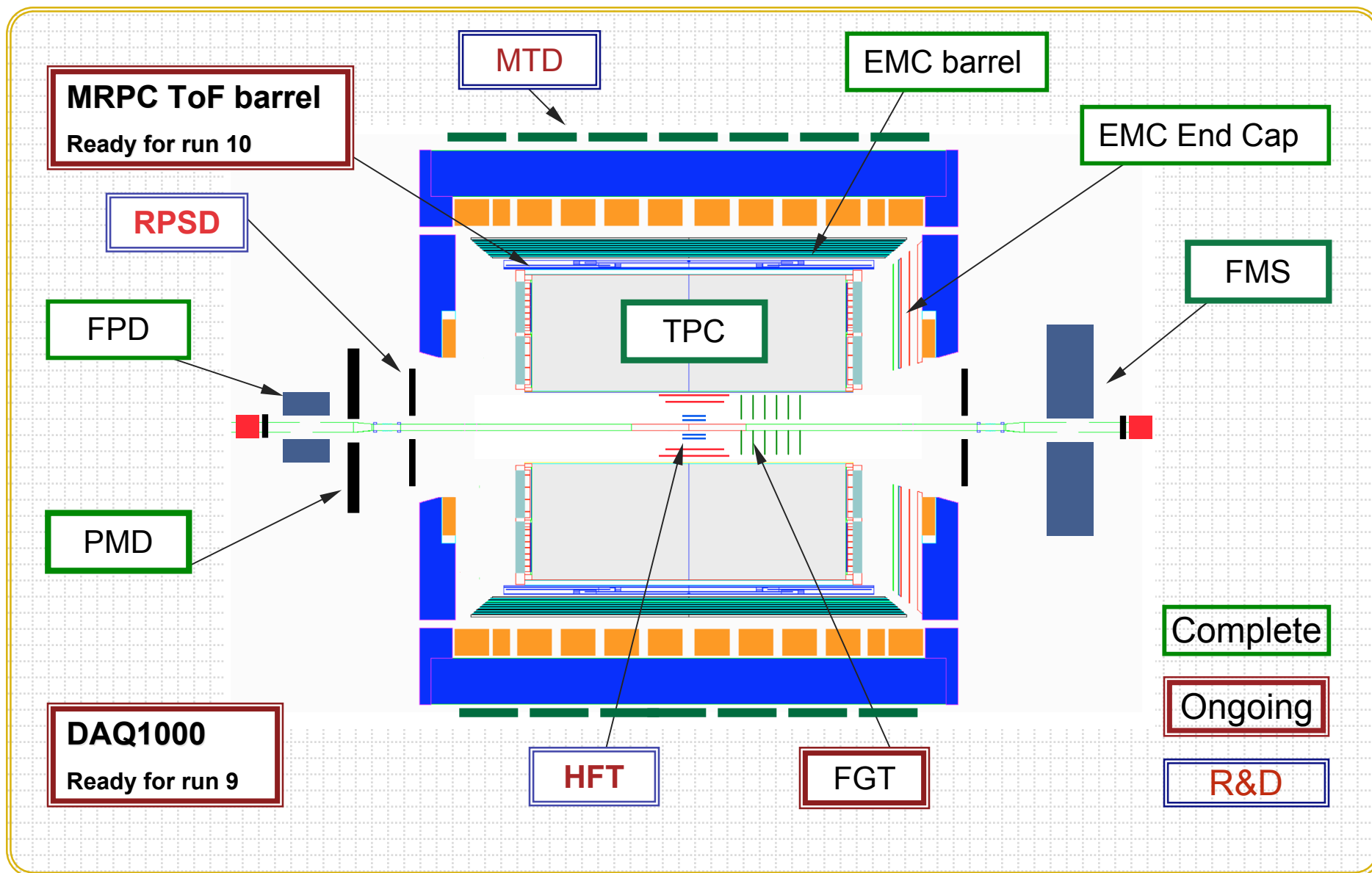
Ready for Physics at Energy Scan



PID will be significantly extended using TOF

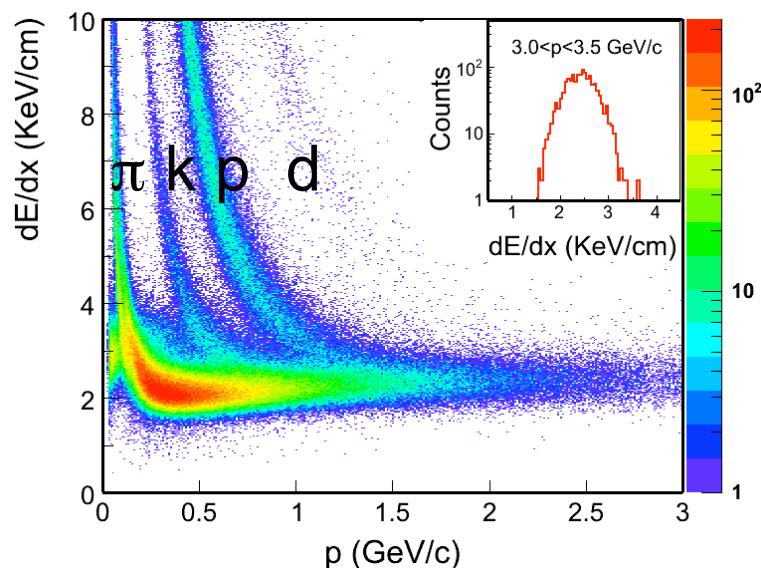
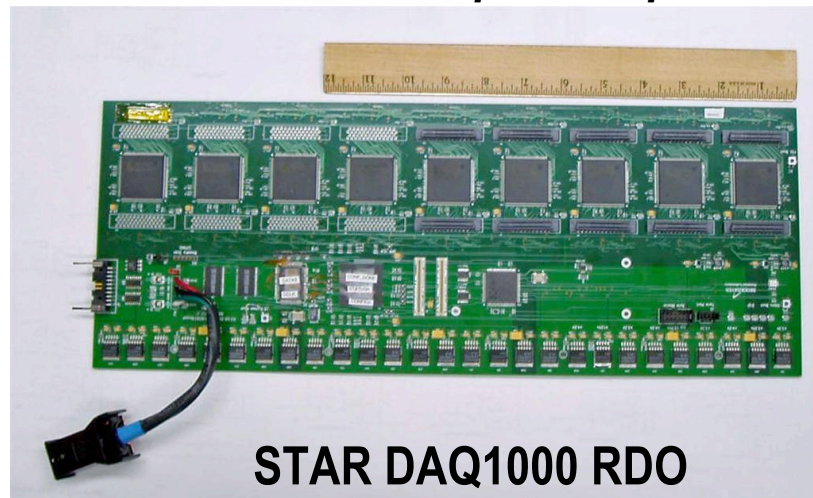
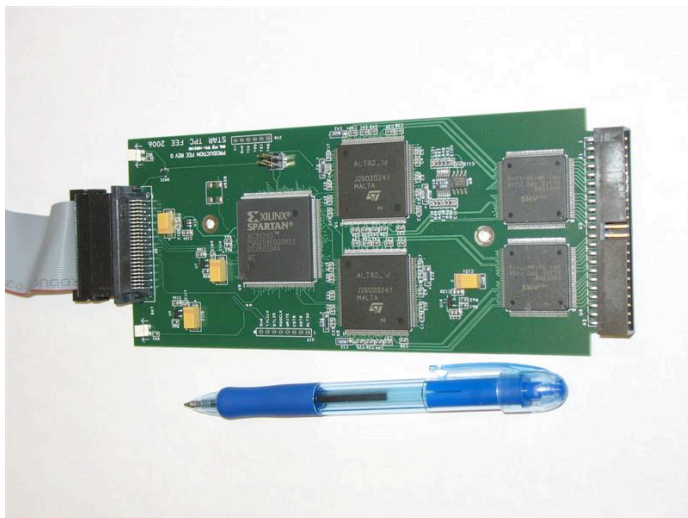
STAR Upgrades

STAR Detector



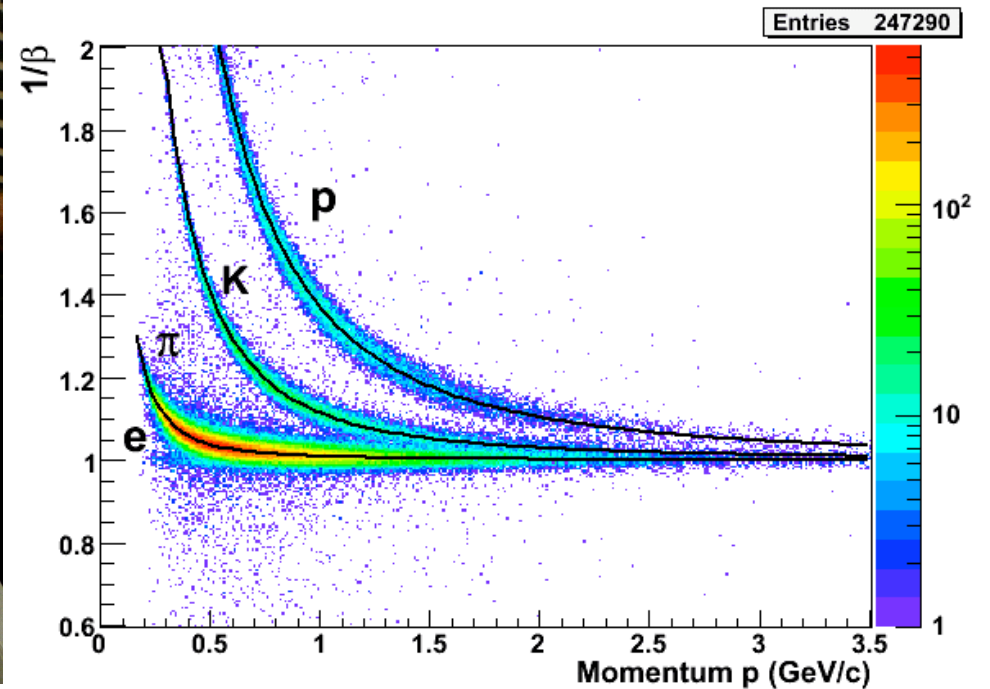
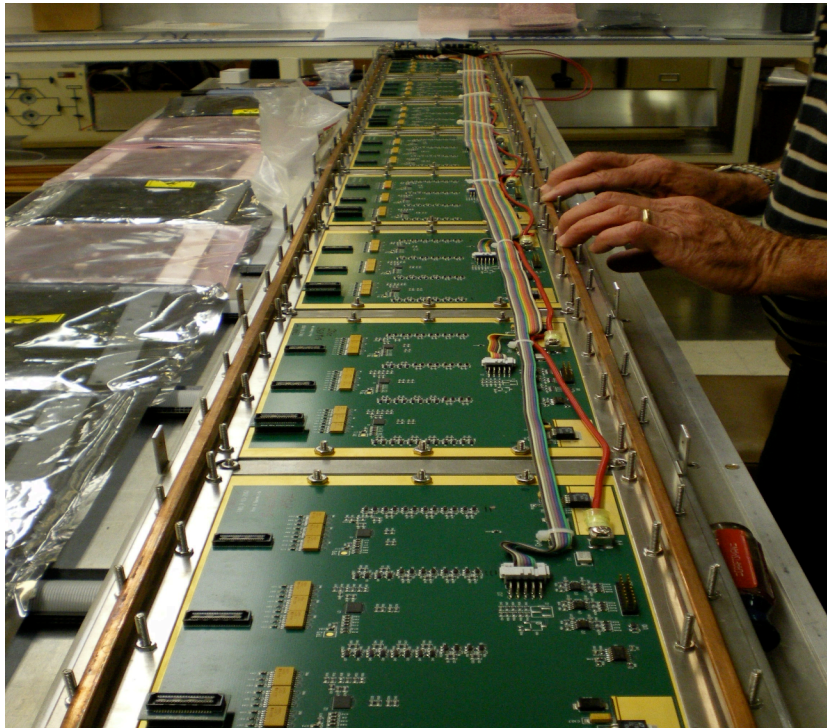
STAR DAQ1000

CERN/ALICE Altro chip development



Run 8 tests:

- One sector of the TPC (1/24) instrumented with DAQ1000 electronics
- Routine operation for physics.
- Speed test: operated at 1 kHz with only 5-7% dead time
- **Full TPC will be instrumented in Run 9**



Run 8 tests:

- Five trays of TOF system installed, commissioned, and used for physics
- Behind sector with DAQ1000 TPC electronics. Routine operation for physics.
- 90 (of 120) ToF trays to be installed for Run 9 and will be completed before Run 10



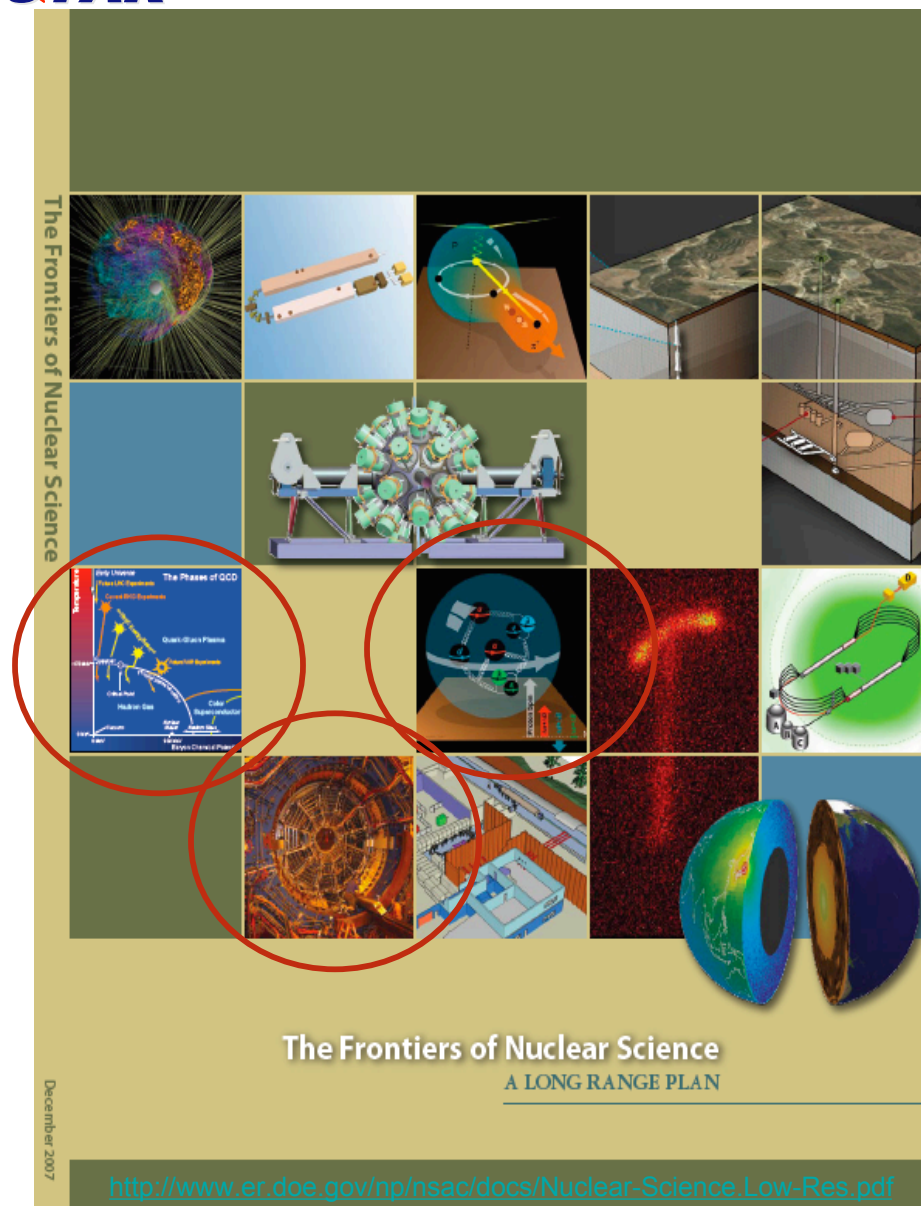
STAR Upgrade Timeline

Upgrade	Completion	Key physics measurements
FMS	Completed 2008	(a) Transverse asymmetry at forward rapidity (b) CGC
TPC DAQ (DAQ1000)	Summer 2008 Ready for Run 09	Large data set, minimal dead time
MRPC TOF	Summer 2009 Full TOF ready for Run 10	Full PID in full azimuthal acceptance (90/120 trays will be used in Run 9) TOF capability is critical for the energy scan
FGT	Summer 2010 Ready for Run 11	Forward W^+ for flavor separated quark polarization
HFT	Summer 2011 Ready for Run 12	(a) Precision hadronic ID for Charm and Bottom hadrons (b) Charm and Bottom hadron energy loss and flow

- 1) Physics
- 2) Upgrades
- 3) Request for new measurements



The Frontiers of Nuclear Science



(I) Systematically study the partonic medium properties at RHIC

(II) Search for QCD critical point

(III) Study proton intrinsic structure



Run 9: 25 Cryo-week (scenario I)

STAR priorities for Runs 9 and 10:

(1) 200 GeV longitudinally polarized p+p

- $\Delta g(x)$

(2) Beam energy scan down to $\sqrt{s}_{NN} \sim 5-6$ GeV

- ***Search for the QCD critical point***

Run	Energy (GeV)	System	Time	Goal
9	$\sqrt{s} = 200$	$p \rightarrow p \rightarrow$	12 week	$50 \text{ pb}^{-1} \text{ P}^4\text{L } 6.5 \text{ pb}^{-1}$
	$\sqrt{s} = 500$	$p \uparrow p \uparrow$	2 week	Commissioning
	$\sqrt{s} = 200$	$p \uparrow p \uparrow$	$\frac{1}{2}$ week	pp2pp
	$\sqrt{s}_{NN} = 200$	Au + Au	3 week	0.3B minbias, 0.5 nb^{-1}
	$\sqrt{s}_{NN} = 5$	Au + Au	$\frac{1}{2}$ week*	Commisioning
10	$\sqrt{s}_{NN} = 39 - 6.1$	Au + Au	14 week	1 st energy scan
	$\sqrt{s}_{NN} = 5$	Au + Au	1 week	Commisioning
	$\sqrt{s}_{NN} = 200$	Au + Au	2 week	200M central
	$\sqrt{s}_{NN} = 200$	Au + Au	1 week	50M central
	$\sqrt{s} = 200$	$p \rightarrow p \rightarrow$	$\frac{1}{2}$ week	pp2pp
	$\sqrt{s} = 500 \text{ or } 200$	$p \uparrow p \uparrow \text{ or } p \rightarrow p \rightarrow$	4 $\frac{1}{2}$ week	Spin studies



Run 9: 16 Cryo-week (scenario II)

Run	Energy (GeV)	System	Time	Goal
9	$\sqrt{s} = 200$	$p \rightarrow p$	11 weeks	50 pb^{-1} , P^4L 6.5 pb^{-1}
	$\sqrt{s} = 200$	$p \uparrow p \uparrow$	$\frac{1}{2}$ week*	pp2pp
10	$\sqrt{s_{NN}} = 39 - 6.1$	Au + Au	12 weeks	1 st energy scan
	$\sqrt{s_{NN}} = 5$	Au + Au	1 week	Commissioning
	$\sqrt{s_{NN}} = 200$	Au + Au	3 $\frac{1}{2}$ weeks	0.5B events, 0.5 nb^{-1}
	$\sqrt{s_{NN}} = 200$	Au + Au	1 week	50M central
	$\sqrt{s} = 500$	$p \uparrow p \uparrow$ or $p \rightarrow p$	5 weeks	Commissioning
	$\sqrt{s} = 200$	$p \uparrow p \uparrow$ or $p \rightarrow p$	$\frac{1}{2}$ week	pp2pp

STAR priorities for Runs 9 and 10:

(1) 200 GeV longitudinally polarized p+p
- $\Delta g(x)$

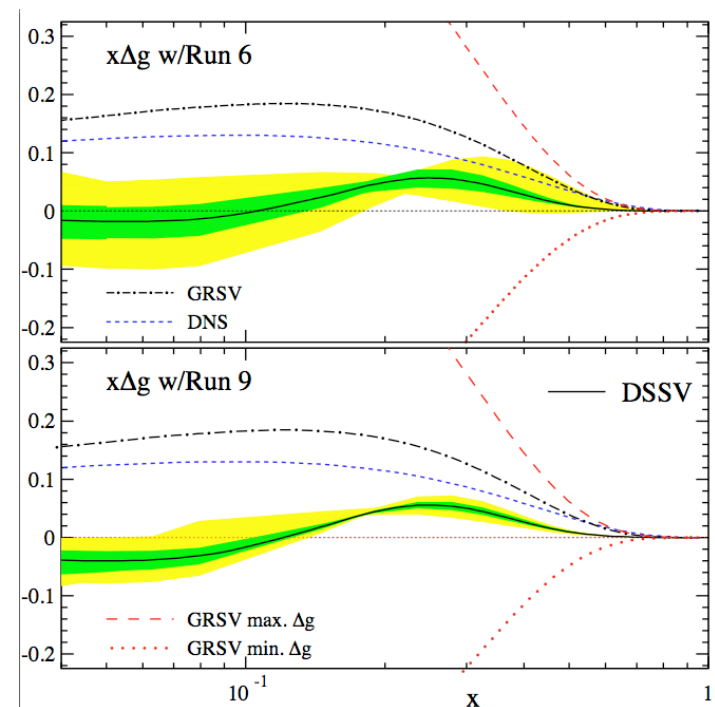
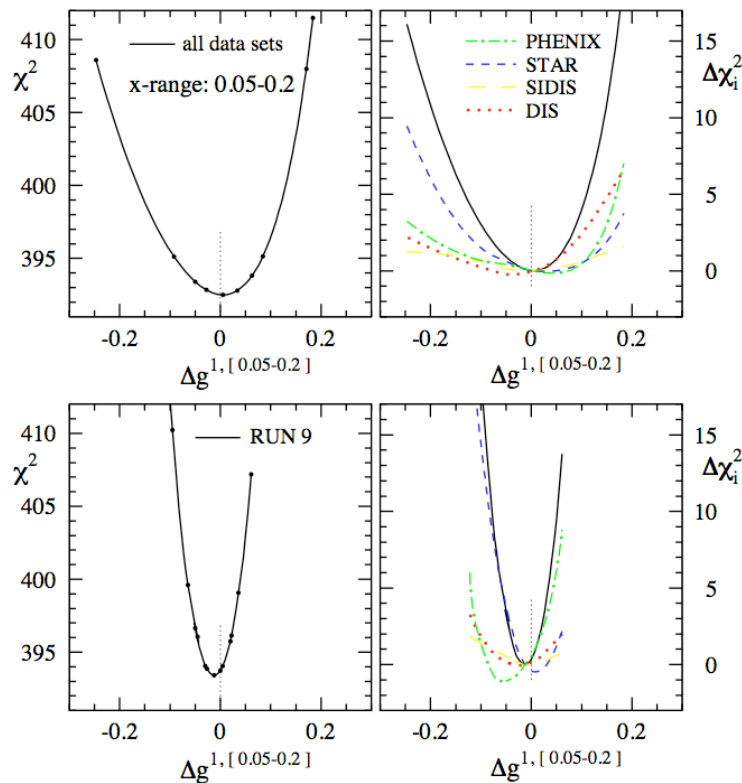
(2) Beam energy scan down to $\sqrt{s_{NN}} \sim 5\text{-}6 \text{ GeV}$
- ***Search for the QCD critical point***



Global Fits with Inclusive RHIC Data

Goals for taking: FoM(Run 9) $\sim 16^*$ FoM(Run 6)

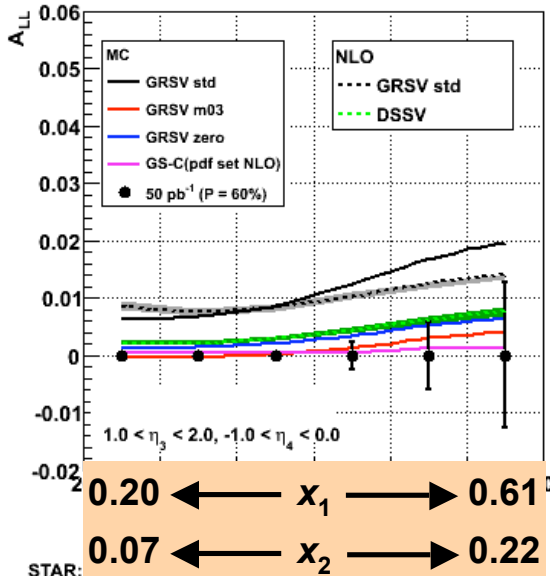
Run 9: STAR bottom line is to collect FoM: 6.5 pb^{-1}
inclusive jet, di-jets, γ -jet... analysis



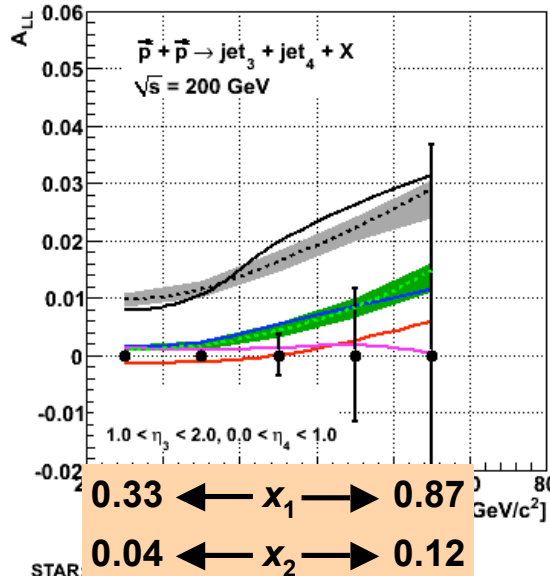


Di-jet Sensitivity in Run 9

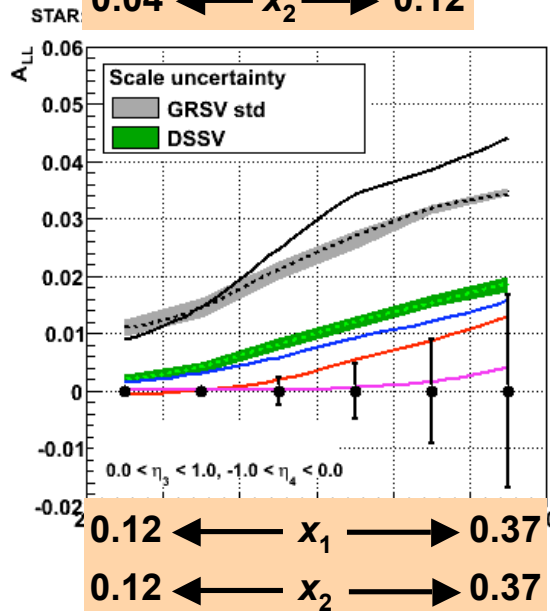
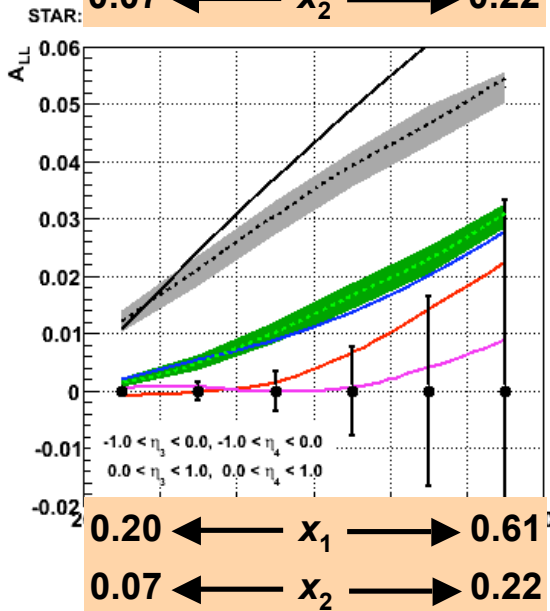
STAR: east barrel - endcap



STAR: west barrel - endcap



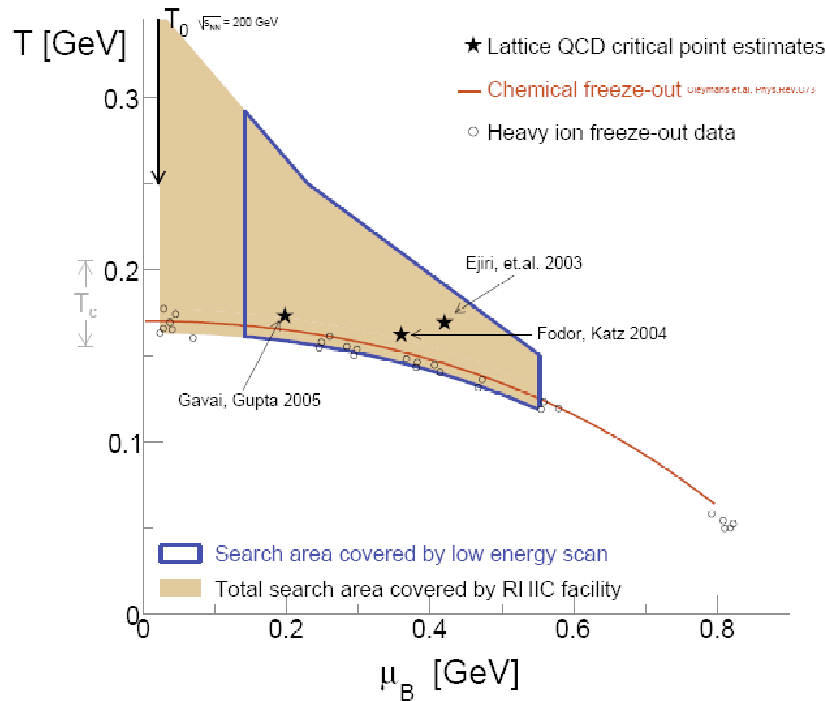
- Di-jets provide **direct access to $\Delta g(x)$** in leading order
- Full NLO asymmetry calculations for di-jets are similar to LO estimates
- Sensitivity is shown for **FoM = $P^4L = 6.5 \text{ pb}^{-1}$**
- Significant discrimination amongst allowed models



Significant contributions at 200 GeV from quark-gluon scattering with highly polarized quarks.



Search for QCD Critical Point at RHIC



STAR Beam Use Request FY10

$\sqrt{s_{NN}}$ [GeV]	μ_B [MeV]	Rate [Hz]	Goal [Events]	Duration [Days]
5.0	550	0.5		7
6.1	491	1.4	1 M	20
7.7	410	2.7	2 M	20
8.6	385	4	2 M	15
12.3	300	10	5 M	15
17.3	229	25	10 M	12
27	151	30	10 M	7
39	112	50	10 M	6

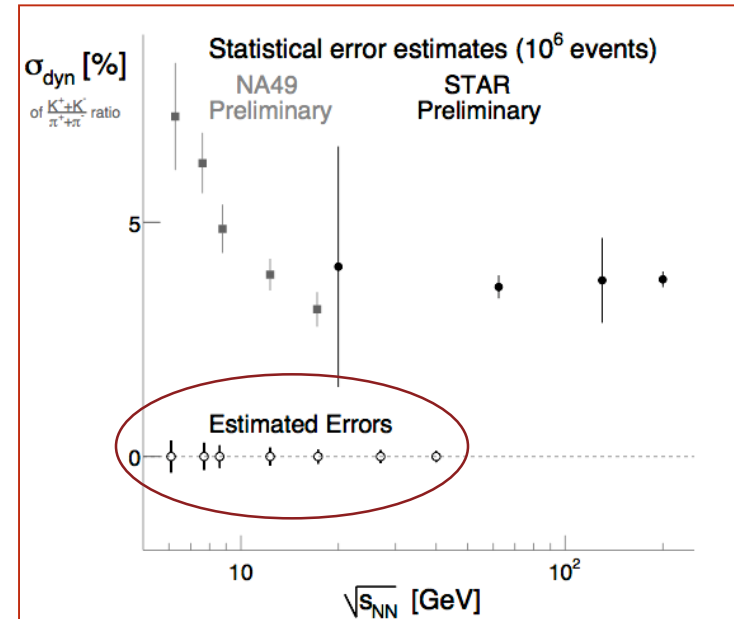
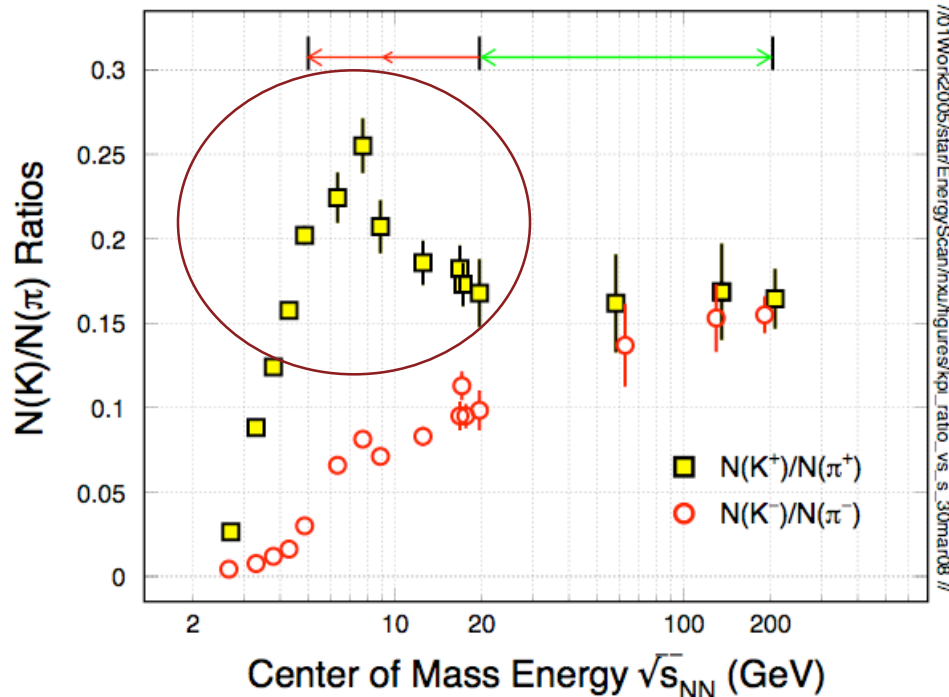
Key measurements:

- (1) All PID hadron spectra and v_2
- (2) K/π , $\langle p_T \rangle$... fluctuations

Strategy:

- (1) From high to low energy, disappearance of high density phenomena (controlled experiment)
- (2) Cover SPS range $\sqrt{s_{NN}} = 5 - 20$ GeV, look for the onset of de-confinement

Hadron Ratios and Fluctuations



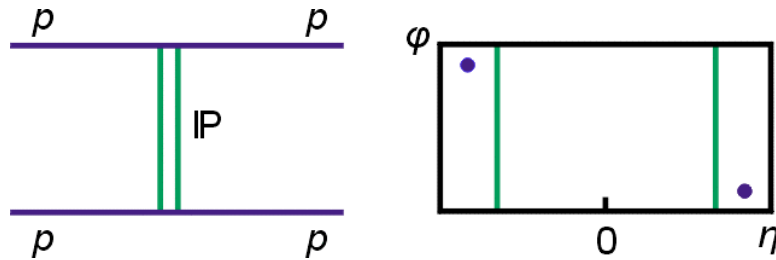
Advantages at STAR:

- Large acceptance: full azimuthal coverage and $|y| < 1.0$
- Clean particle identification: (TPC, ToF, EMC)
- Continuity from high to low energy scan, systematic errors under control
- High potential for discovery

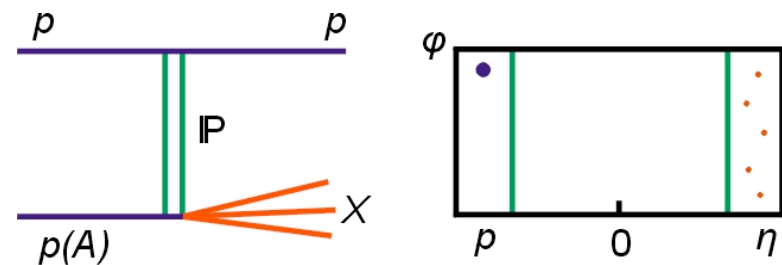


Tagged Forward Protons Physics

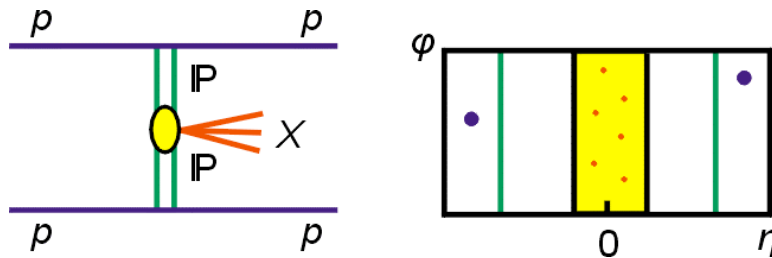
Elastic and Inelastic Processes



Elastic Scattering: Roman Pots only



Single Diffraction: RP + FMS or RP + BBC

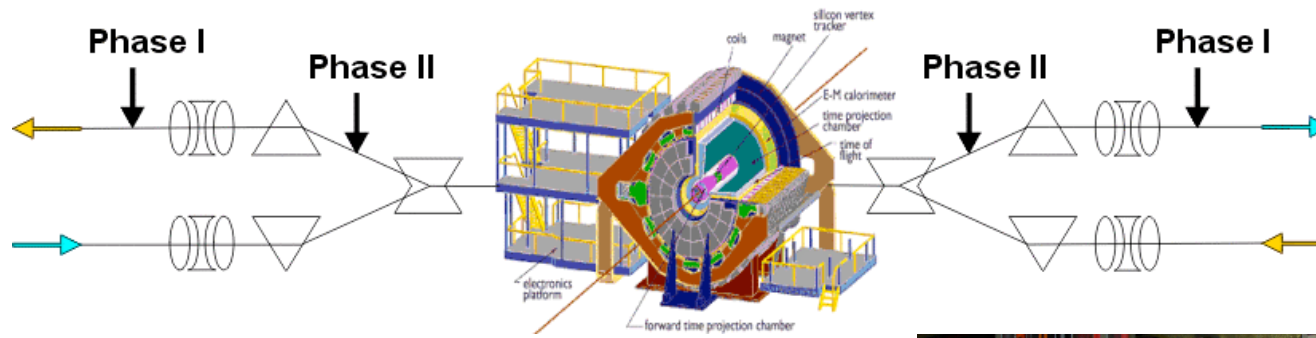


For each proton vertex one has
 t four-momentum transfer
 $\xi = \Delta p/p$ - proton momentum loss
 M_X invariant mass

Central Production: RP + ToF; Tracks in the TPC **full acceptance**

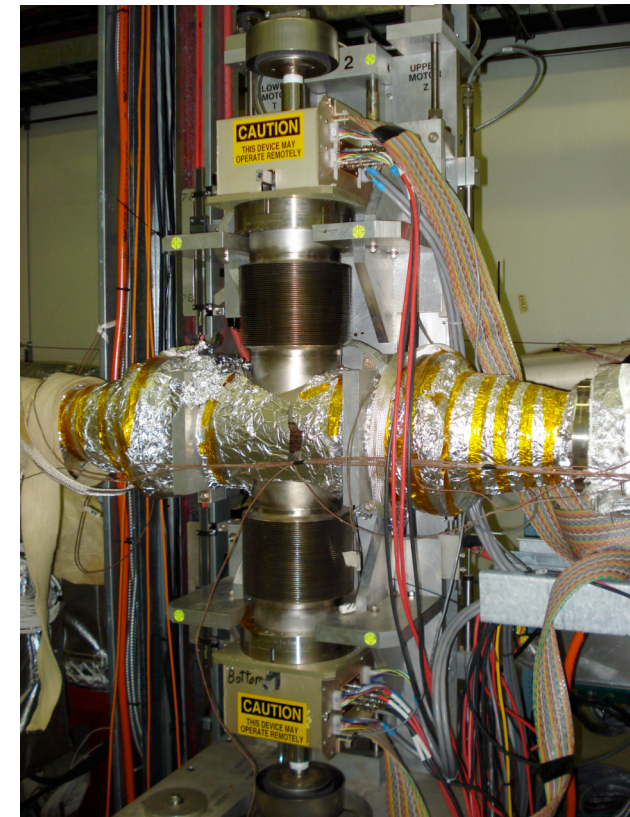
In terms of QCD, Pomeron exchange consists of the exchange of a color singlet combination of gluons. Hence, triggering on forward protons at high (RHIC) energies predominantly selects exchanges mediated by **gluonic matter**.

Status of pp2pp



- Roman Pots (RP) were installed East and West of STAR (Phase I);
- pp2pp integrated into trigger and DAQ;
- Inserted pots into the beam pipe during last 2 hours of Run 8 (pp):
 - ***Triggered on elastic and inelastic coincidences in pp2pp RP***
 - ***No impact on background levels in STAR mid-rapidity detectors***

Phase II: Install RP between DX-D0 magnets, allowing to trigger on forward protons with standard tune, hence taking data with STAR without need for dedicated time.





Pp2pp Plan for Runs 9 and/or 10

A dedicated **1/2 week run**, including setup of $\beta^*=20\text{m}$ optics, and about 30 hrs of data taking will produce:

1. Elastic scattering:

- 100% acceptance for elastic scattering for $0.003 < |t| < 0.024$;
- **40×10^6** elastic events: $\Delta b = 0.31 \text{ (GeV/c)}^{-2}$, $\Delta p = 0.01$, $\Delta \sigma_{\text{tot}} = 2\text{-}3 \text{ mb}$;
- In eight t subintervals we shall have $\sim 5 \times 10^6$ events in each resulting in corresponding errors $\delta A_n = 0.0017$, $\delta A_{nn} = \delta A_{ss} = 0.003$.

2. DPE process: (luminosity $2 \times 10^{29} \text{ cm}^{-2}\text{sec}^{-1}$)

- About **$1 \cdot 10^6$** events with the proton tag on each side, proton in either pot;
- **$3 \cdot 10^5$** DPE events with fully reconstructed proton momentum.



Runs 11 - 13 (30 cryo-week/yr)

Run	Energy (GeV)	System	Time	Goal
11	$\sqrt{s} = 200$	$p_{\uparrow} p_{\uparrow}$ or $p_{\rightarrow} p_{\rightarrow}$	6 week	20-30 pb ⁻¹
	$\sqrt{s} = 500$	$p_{\uparrow} p_{\uparrow}$ or $p_{\rightarrow} p_{\rightarrow}$	15 week	150 pb ⁻¹
	$\sqrt{s_{NN}} = 200$	U + U	2 week	Commissioning
12	$\sqrt{s_{NN}} = 200$	Au + Au	12 week	0.5B minbias, 5 nb ⁻¹
	$\sqrt{s_{NN}} = 39 - 5$	Au + Au	13 week	2 nd energy scan
13	$\sqrt{s} = 200$	$p_{\uparrow} p_{\uparrow}$ or $p_{\rightarrow} p_{\rightarrow}$	13 week	2B minbias, 100 pb ⁻¹
	$\sqrt{s} = 500$	$p_{\uparrow} p_{\uparrow}$ or $p_{\rightarrow} p_{\rightarrow}$	12 week	300 pb ⁻¹

Run 11: (i) 1st measurement of flavor dependence of sea q/anti-q polarization in the proton at $\sqrt{s} = 500$ GeV *p+p collisions*
(ii) HFT prototyping in $\sqrt{s_{NN}} = 200$ GeV *U+U collisions*

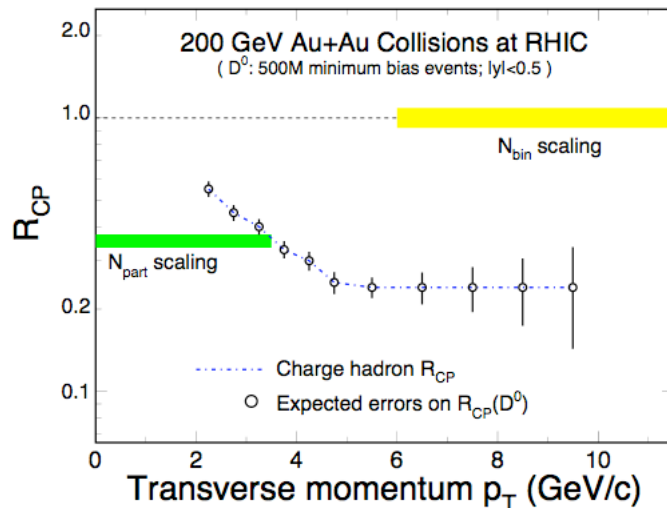
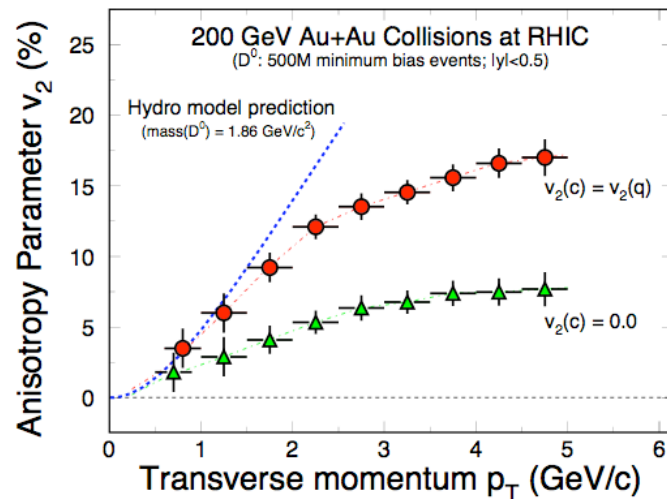
Run 12: *Anticipating RHIC-II high luminosity*

- (i) 1st HFT physics measurements of charm hadron $v_2(p_T)$ and $R_{CP}(p_T)$ in $\sqrt{s_{NN}} = 200$ GeV *Au+Au collisions*
- (ii) Focused energy-scan in the search for the QCD critical point.
Prior accelerator development is crucial at $\sqrt{s_{NN}} = 5-6$ GeV
- (iii) gamma-jet and quarkonia states measurements

Run 13: (i) HFT physics reference measurement of charm hadron spectra in $\sqrt{s} = 200$ GeV pp collisions; complete remaining $\sqrt{s} = 200$ GeV spin milestones.
(ii) Measurement of the x dependence of W production at $\sqrt{s} = 500$ GeV

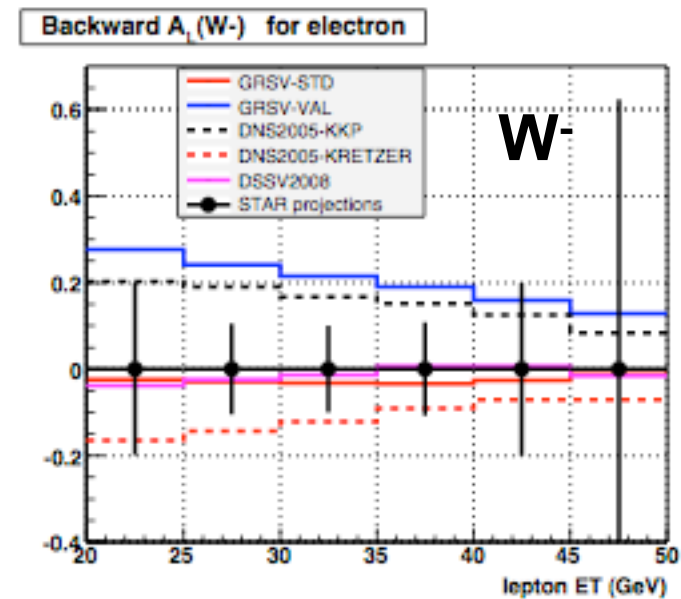
Future Physics Goals

Heavy Flavor



W[±] Physics

L=300 pb⁻¹, pol.~ 70%



Plan to be accomplished
In Runs 11-13



Goals for Runs 9 and 10

STAR priorities for Runs 9 and 10:

(1) 200 GeV longitudinally polarized p+p

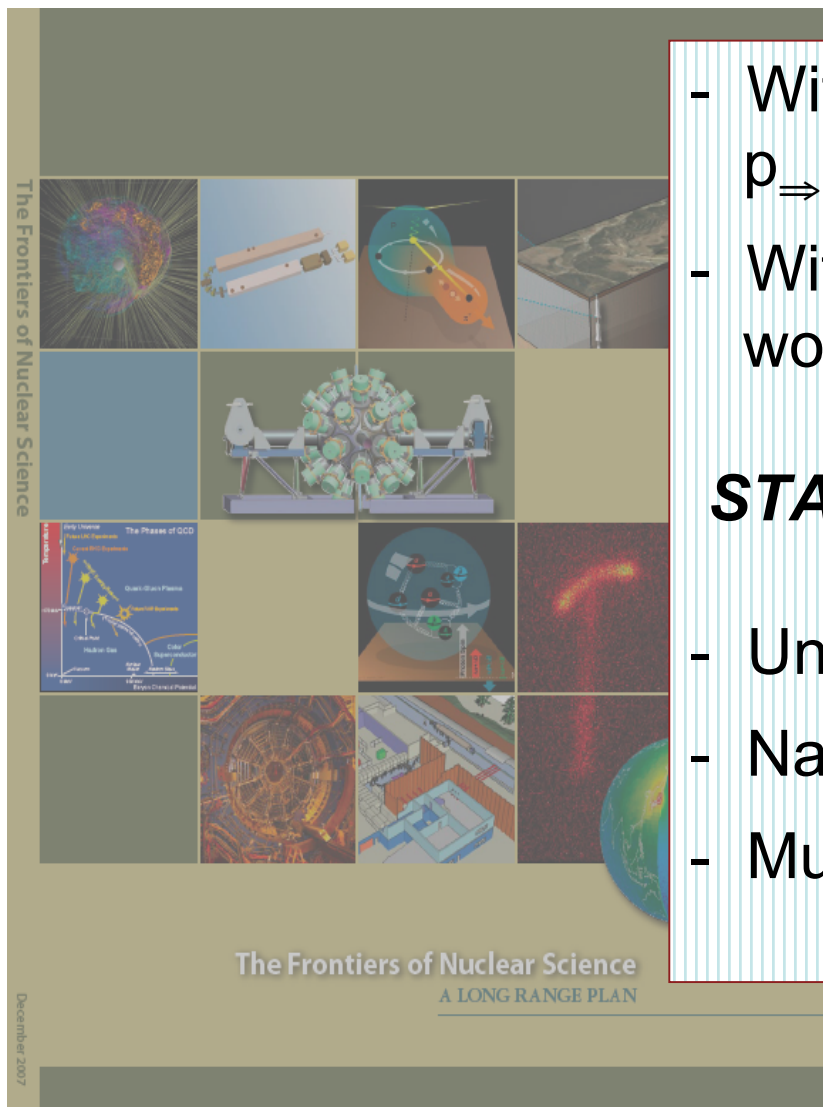
- $\Delta g(x)$

(2) Beam energy scan down to $\sqrt{s_{NN}} \sim 5$ GeV

- ***Search for the QCD critical point***

(3) Top energy, high statistics Au+Au data set

Summary



- Without high stat. 200 GeV $p_{\Rightarrow} + p_{\Rightarrow}$, we won't know $\Delta g(x)$
- Without energy scan to 5 GeV, we won't find ***the QCD critical point***

STAR at the QCD Lab:

- Unique physics program
- National priorities
- Must be done in a timely fashion